EXHIBIT F

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(54) **METHOD AND APPARATUS FOR IMPROVING EFFICIENCY IN A SWITCHING REGULATOR AT LIGHT LOADS**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,562,668	A	2/1971	Bartlett et al.
3,733,519	A	5/1973	Griffey
3,733,540	A	5/1973	Hawkins
3,909,696	A	9/1975	Katou et al.
3,959,716	A	5/1976	Gilbert, Jr. et al.
4,031,463	A	6/1977	Norberg
4,037,271	A	7/1977	Keller
4,058,758	A	11/1977	Peterson
4,063,307	A	12/1977	Stephens
4,079,294	A	3/1978	Teuling
4,079,596	A	3/1978	Cheng et al.
4,087,850	A	5/1978	Koizumi
4,156,273	A	5/1979	Sato
4,251,743	A	2/1981	Hareyama
4,263,644	A	4/1981	Zellmer
4,263,655	A	4/1981	Chappell, Jr.
4,288,831	A	9/1981	Dolikian
4,302,803	A	11/1981	Shelly
4,315,303	A	2/1982	Snyder

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0 583 038 A1	2/1994
EP	01 91 0877	2/2006
JP	10-014217	1/1998
JP	11-155281	6/1999
JP	11215820	8/1999
WO	PCT/US01/05133	5/2001

OTHER PUBLICATIONS

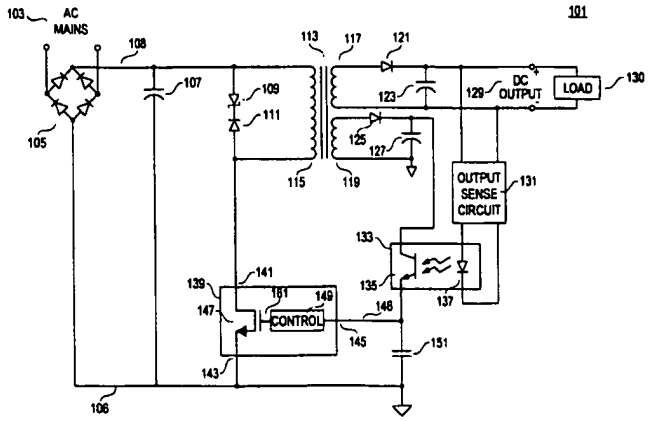
JP 2002-507504, Notice of the Reason for Refusal (with English Translation), Aug. 28, 2007.

(Continued)

Primary Examiner—My-Trang Ton

(57) **ABSTRACT**

A switching regulator that operates at a frequency for a first range of feedback signal values and at a variable frequency without skipping cycles for a second range of feedback signal values. In one embodiment, a switching regulator for a switched mode power supply includes a power switch coupled between drain and source terminals of the switching regulator, which are to be coupled to control the delivery of power to an output of a power supply. A control terminal of the switching regulator is to be coupled to an output of the power supply. The switching regulator includes a control circuit coupled to the control terminal and generates a feedback signal that is responsive to the output of the power supply. The control circuit also generates a drive signal that is coupled to control the switching of the power switch. The control circuit generates the drive signal responsive to the feedback signal. The drive signal has a fixed frequency for a first range of feedback signal values and at a variable frequency without skipping cycles for a second range of feedback signal values.



U.S. PATENT DOCUMENTS

4,347,559	A	8/1982	Sturgeon
4,400,767	A	8/1983	Fenter
4,415,960	A	11/1983	Clark, Jr.
4,447,841	A	5/1984	Kent
4,450,514	A	5/1984	Peruth
4,456,872	A	6/1984	Froeschle
4,459,651	A	7/1984	Fenter
4,479,174	A	10/1984	Cates
4,536,700	A	8/1985	Bello et al.
4,541,041	A	9/1985	Park et al.
4,578,630	A	3/1986	Grosch
4,593,347	A	6/1986	Peruth et al.
4,649,464	A	3/1987	Shono
4,672,518	A	6/1987	Murdock
4,679,131	A	7/1987	Filliman
4,685,040	A	8/1987	Steigerwald et al.
4,717,994	A	1/1988	Diaz et al.
4,733,104	A	3/1988	Steigerwald et al.
4,739,465	A	4/1988	Asano et al.
4,763,238	A	8/1988	Maige
4,764,846	A	8/1988	Go
4,772,995	A	9/1988	Gautherin et al.
4,809,150	A	2/1989	Limuti et al.
4,819,122	A	4/1989	Gontowski, Jr.
4,823,070	A	4/1989	Nelson
4,849,869	A	7/1989	Tanuma et al.
4,928,200	A	5/1990	Redl et al.
4,937,728	A	6/1990	Leonardi
4,942,508	A	7/1990	Nakamura
4,956,761	A	9/1990	Higashi
4,959,606	A	9/1990	Forge
4,975,823	A	12/1990	Rilly et al.
4,980,791	A	12/1990	Alberkrack et al.
4,996,638	A	2/1991	Orr
5,012,401	A	4/1991	Barlage
5,034,871	A	7/1991	Okamoto et al.
5,079,453	A	1/1992	Tisinger et al.
5,245,526	A	9/1993	Balakrishnan et al.
5,282,107	A	1/1994	Balakrishnan
5,285,366	A	2/1994	Zaretsky
5,285,369	A	2/1994	Balakrishnan
5,297,014	A	3/1994	Saito et al.
5,313,381	A	5/1994	Balakrishnan
5,335,162	A	8/1994	Martin-Lopez et al.
5,408,402	A	4/1995	Nonnenmacher
5,412,556	A	5/1995	Marinus
5,414,342	A	5/1995	Mammano et al.
5,414,611	A	5/1995	Muto et al.
5,430,633	A	7/1995	Smith
5,469,349	A	11/1995	Marinus
5,481,178	A	1/1996	Wilcox et al.
5,498,995	A	3/1996	Szepesi et al.
5,532,626	A	7/1996	Khayat
5,568,044	A	10/1996	Bittner
5,617,016	A	4/1997	Borghi et al.
5,633,788	A	5/1997	Tanaka et al.
5,657,215	A	8/1997	Faulk
5,675,479	A	10/1997	Tani et al.
5,675,485	A	10/1997	Seong
5,717,578	A	2/1998	Afzal
5,731,694	A	3/1998	Wilcox et al.
5,742,494	A	4/1998	Brakus et al.
5,745,352	A	4/1998	Sandri et al.
5,747,977	A	5/1998	Hwang
5,748,461	A	5/1998	Preller
5,751,565	A	5/1998	Faulk
5,784,232	A	7/1998	Farr
5,798,635	A	8/1998	Hwang et al.
5,835,361	A	11/1998	Fitzgerald
5,859,768	A	1/1999	Hall et al.
5,901,051	A	5/1999	Takahashi et al.
5,912,552	A	6/1999	Tateishi
5,920,466	A	7/1999	Hirahara
5,973,945	A	10/1999	Balakrishnan et al.
5,995,384	A	11/1999	Majid et al.
5,995,387	A	11/1999	Takahashi et al.
5,999,421	A	12/1999	Liu
6,008,590	A	12/1999	Giannopoulos et al.
6,011,706	A	1/2000	Adragna et al.
6,094,362	A	7/2000	Domingo
6,100,675	A	8/2000	Sudo
6,100,678	A	8/2000	Hobrecht
6,118,675	A	9/2000	Lionetto et al.
6,127,816	A	10/2000	Hirst
6,130,528	A	10/2000	Aoyama
6,134,123	A	10/2000	Yamada
6,147,883	A	11/2000	Balakrishnan et al.
6,188,587	B1	2/2001	Yun et al.
6,198,265	B1	3/2001	Stevenson
6,307,356	B1	10/2001	Dwelley

OTHER PUBLICATIONS

Abraham I Pressman, *Switching Power Supply Design*, McGraw–Hill, Inc. (1998).

Linear Technology's LT1070/LT1071 Data Sheet (1989) ("LT1070 Data Sheet").

Linear Technology's LT1072 Data Sheet (1988) ("LT1072 Data Sheet").

John D. Lenk, Simplified *Design of Switching Power Supplies*, Butterworth–Heinemann (1995).

Balu Balakrishnan, *Three Terminal Off–Line Switching Regulator Reduces Cost and Parts Count*, Official Proceedings of the Twenty–Ninth International Power Conversion Conference, at 267 (1994).

Balu Balakrishnan, *Low–power switchers expand reach*, Electronic Engineering Times, Aug. 29m 1994, at 52.

Design of Isolated Converters Using Simple Switchers, Application Note 1095, National Semiconductor (Aug. 1998) ("LM285X Data Sheet").

CS5124/6 Data Sheet, Cherry Semiconductor (1999) (CS5124 Data Sheet).

Irving M. Gottlieb, *Power Supplies, Switching Regulators, Inverters, and Converters*.

Panov and Jovanovic, *Adaptive Off–Time Control For Variable–Frequency, Soft–Switched Flyback Converter At Light Loads*, 1999 IEEE.

Xunwei Zhou, Mauro Donati, Luca Amoroso, Fred C. Lee, *Improved Light Load Efficiency for Synchronous Rectifier Buck Converter*, 1 Fourteenth Annual Applied Power Electronic Conference and Exposition, IEEE, at 295 (2000).

Wayne M. Austin, *Variable–pulse modulator improves power–supply regulation*, Jun. 25, 1987.

F. J. De Stasi, T. Szepesi, *A 5A 100 KHZ Monolithic Bipolar DC/DC Converter*, The European Power Electronics Association (1993).

Unitrode Current Mode PWM Spec sheet for US1846/7, UC2846/7, UC3836/7.

Motorola, Inc., A 100 kHz FET Switcher, TDT–101 TMOS Power Fet Design Tips sheet.

M. Goodman and O. Kuhlmann, *Current mode control of switching regulators*, IEEE, Oct. 1984.

Micro Linear preliminary spec sheet, ML4803, 8–Pin PFC and PWM Controller Combo, Feb. 1999.

Fairchild Advance Specification for FAN7554/D product, Rev. 0.1, 2000.

Robert Boschert, *Flyback converters: Solid–state solution to low–cost switching power supplies*, Electronics, Dec. 21, 1978.
Ravindra Ambatipudi, Improving Transient Response of Opto–Isolated Converters, PC/M May 1997.
Linear Technology's LT1070/LT1071 Design Manual, Application Note 19, Jun. 1986.
Linear Technology's LT1241 Data Sheet.
Jim Williams, *Regulator IC speeds design of switching power supplies.*
Carl Nelson, *Switching controller chip handles 100W from a 5–pin package*, Electronic Design, Dec. 26, 1985.
Keith Billings, *Switchmode Power Supply Handbook*, McGraw–Hill, Inc. (1989).
Siemens TDA 4714 C, TDA 4716 C, Sep. 1994.
Siemens TDA 4718 A, Dec. 1995.
Texas Instruments TL5001, TL5001A.
R. Mammano, Application Note U–150, Applying the UCC3570 Voltage–Mode PWM Controller to both Off–line and DC/DC Converter Designs.
Unitrode Corporation UCC1570/UCC2570/UCC3570 Data Sheet—Apr. 1999, Revised Jul. 2000.
Unitrode Corporation UCC1809–1/–2/ UCC2809–1/–2/ UCC3809–1/12 Data Sheet—Nov. 1999.
L. Calderoni, L. Pinol, V. Varoli, *Optimal Feed–Forward Compensation for PWM DC/DC Converters*, IEEE, 1990.
L. Calderoni, L. Pinol, V. Varoli, *Optimal Feed–Forward Compensation for PWM DC/DC Converters with "Linear" and "Quadratic" Conversion Ratio*, IEEE, 1992.
Siemens Application Note TDA 4718 and SIPMOS FET.
Siemens IC for Switched–Mode Power Supplies spec.
Siemens Control IC for Single–Ended and Push–Pull Switched–Mode Power Supplies.
Maige, Philippe, "A Universal Power Supply Integrated Circuit for TV and Monitor Applications".
De Stasi, et al. "A 5A 100 Khz monolithic bipolar DC/DC converter".
Linear Technology 5A and 2.5A High Efficiency Switching Regulators.
LM2825 Application Information Guide.
Design of Isolated Converters Using Simple Switchers.
Motorola—Low cost 1.0 A Current Source for Battery Chargers.
Infineon Technologies Application Note: AN–SMPS–1693X–1.
Cherry Semiconductor High Performance, Integrated Current Mode PWM Controllers.
Cherry Semiconductor High Performance, Integrated Current Mode PWM Controllers CS5124/6.
Cherry Semiconductor High Performance, Integrated Current Mode PWM Controllers.
Abstract data sheet for FA3641P.
Fairchild Semiconductor FAN7554/D Versatile PWM Controller.
Boschert, Robert. "Flyback converters: solid–state solution to low–cost switching power supplies," *Electronics*, Dec. 21, 1973.
Ambatipudi, Ravindra, Improving Transient Response of Opto–Isolated Converters.
National Semiconductor LM2825 Integrated Power Supply 1A DC–DC Converter.
Linear Technology LT 1070 Design Manual.
Linear Technology data sheet—5A and 2.5A High Efficiency Switching Regulators.
Williams, Jim, "Regulator IC speeds design of switching power supplies".
Nelson, Carl "Switching controller chip handles 100 W for a 5–pin package".
Mammano, Robert A., Application Note U–150 Applying the UCC3570 Voltage–Mode PWM Controller to Both Off–Line and DC/DC Converter Designs.
Unitrode Corporation UCC1570/UCC2570/UCC3570—Low Power Pulse Width Modulator—data sheet (Apr. 1999, Revised Jul. 2000).
STMicroelectronics, VIPer100/SP, VIPer100A/ASP data sheet (May 1999).
Balakrishnan, Balu, *Next Generation, Monolithic Off–Line Switcher Improves Performance, Flexibility*, PCIM, Apr. 2000.
FA3641P(N), FA3647P(N) Spec Sheet.
Linear Technology's LT1074/LT1076 Data Sheet (1994).
Xunwei Zhou, Mauro Donati, Luca Amoroso, and Fred C. Lee, *Improve Light Load Efficiency for Synchronous Rectifier Buck Converter*, IEEE, 295–302 (1999).
Keith Billings, Switchmode Power Supply Handbook, McGraw–Hill, Inc. (1989) 2.210–2.219.
Zhou et al, "Improve Light Load Efficiency for Synchronous Rectifier Buck Converter," Fourteenth Annual Applied Power Electronics Conference and Exposition, IEEE (Mar. 1999).

EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

Claims **1** and **17** are determined to be patentable as amended.

Claims **2–3**, **6**, **9**, **18** and **19**, dependent on an amended claim, are determined to be patentable.

New claims **30–52** are added and determined to be patentable.

Claims **4**, **5**, **7**, **8** **10–16** and **20–29** were not reexamined.

1. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply;

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal**[**,**]**; *and*

an oscillator circuit included in the control circuit for controlling both a switching frequency and a maximum duty cycle of the power switch,

wherein the control circuit *is* coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values *when the output of the power supply is in regulation, and wherein* the control circuit *is* coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values *when the output of the power supply is in regulation.*

17. A method for regulating a power supply, comrpising:

switching with a drive signal a power switch coupled to an energy transfer element of the power supply to control power delivered to an output of the power supply;

generating a feedback signal in response to the output of the power supply;

maintaining a frequency of the drive signal at a fixed frequency for a first range *of* feedback signal values **[**and**]** *when the output of the power supply is in regulation*;

varying the frequency of the drive signal without skipping cycles in response to the feedback signal for a second range of feedback signal values *when the power supply output is in regulation; and*

controlling both the frequency of the drive signal and a maximum duty cycle of the power switch with an oscillator circuit of a controller of the power supply.

30. The switching regulator of claim 1 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

31. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply; and

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal, the control circuit coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values, the control circuit coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values, wherein the control circuit comprises:

a feedback signal circuit coupled to the third terminal, the feedback signal circuit coupled to generate the feedback signal; and

a pulse width modulator circuit coupled to switch the power switch in response to the feedback signal,

wherein the first and second ranges of the feedback signal correspond to first and second ranges of on-time values of a drive signal generated by the pulse width modulator circuit to switch the power switch.

32. The switching regulator of claim 31 wherein the first and second ranges of the feedback signal further correspond to first and second ranges of duty cycle percentage values of the drive signal generated by the pulse width modulator circuit to switch the power switch.

33. The switching regulator of claim 31 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

34. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power suply and the second terminal to be coupled to a supply rail of the power supply; and

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal, the control circuit coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values, the control circuit coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values, wherein the control circuit comprises:

a feedback signal circuit coupled to the third terminal, the feedback signal circuit coupled to generate the feedback signal; and

a pulse width modulator circuit coupled to switch the power switch in response to the feedback signal, and

wherein on-time and off-time values of a drive signal generated by the pulse width modulator circuit to switch the power switch vary simultaneously as a

function of a level of a load coupled to the output of the power supply to vary the switching frequency of the power switch without skipping cycles for the second range of feedback signal values.

35. The switching regulator of claim 34 wherein the off-time value of the drive signal is varied as a function of the on-time value and a first on-time value of the drive signal, the first on-time value of the drive signal corresponding to an on-time of the drive signal at a boundary between the first and second ranges of feedback signal values.

36. The switching regulator of claim 34 wherein the switching frequency of the power switch is reduced without skipping cycles to a minimum frequency when a duty cycle percentage value of the drive signal generated by the pulse width modulator circuit to switch the power switch is substantially equal to zero percent.

37. The switching regulator of claim 34 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

38. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply; and

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal, the control circuit coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values, the control circuit coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values, wherein the first and second ranges of the feedback signal correspond to first and second ranges of on-time values of a drive signal generated by the control circuit to switch the power switch.

39. The switching regulator of claim 38 wherein the first and second ranges of the feedback signal further correspond to first and second ranges of duty cycle percentage values of the drive signal generated by the control circuit to switch the power switch.

40. The switching regulator of claim 38 wherein the control circuit comprises an oscillator circuit for controlling both the switching frequency and a maximum duty cycle of the power switch.

41. The switching regulator of claim 38 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

42. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply; and

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal, the control circuit coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values, the control circuit coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values, wherein on-time and off-time values of a drive signal generated by the control circuit to switch the power switch vary simultaneously as a function of the feedback signal in the second range of feedback signal values.

43. The switching regulator of claim 42 wherein the off-time value of the drive signal is varied as a function of the on-time value and a first on-time value of the drive signal, the first on-time value of the drive signal corresponding to an on-time of the drive signal at a boundary between the first and second ranges of feedback signal values.

44. The switching regulator of claim 42 wherein the switching frequency of the power switch is reduced without skipping cycles to a minimum frequency when a duty cycle percentage value of the drive signal generated by the control circuit to switch the power switch is substantially equal to zero percent.

45. The switching regulator of claim 42 wherein the control circuit comprises an oscillator circuit for controlling both the switching frequency and a maximum duty cycle of the power switch.

46. The switching regulator of claim 42 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

47. A switching regulator, comprising:

a power switch coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply;

a control circuit coupled to a third terminal and the power switch, the third terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal; and

an oscillator circuit included in the control circuit for controlling both a switching frequency and an on-time of the power switch,

wherein the control circuit is coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values when the output of the power supply is in regulation, and wherein the control circuit is coupled to vary a switching frequency of the power switch without skipping cyles in response to the feedback signal for a second range of feedback signal values when the output of the power supply is in regulation.

48. The switching regulator of claim 47 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

49. The switching regulator of claim 47 wherein the first and second ranges of the feedback signal correspond to first and second ranges of on-time values of a drive signal generated by the control circuit to switch the power switch.

50. A switching regulator, comprising:

a single power switch to be coupled between first and second terminals, the first terminal to be coupled to an energy transfer element of a power supply and the second terminal to be coupled to a supply rail of the power supply;

a control circuit coupled to a third terminal of the switching regulator and to the single power switch, the third

terminal to be coupled to an output of the power supply, the control circuit coupled to generate a feedback signal responsive to the output of the power supply, the control circuit coupled to switch the power switch in response to the feedback signal, the control circuit coupled to switch the power switch at a fixed switching frequency for a first range of feedback signal values when the output of the power supply is in regulation, the control circuit coupled to vary a switching frequency of the power switch without skipping cycles in response to the feedback signal for a second range of feedback signal values when the power supply output is in regulation,

wherein the control circuit comprises an oscillator circuit for controlling both the switching frequency and a maximum duty cycle of the power switch.

51. The switching regulator of claim 50 wherein a lowest switching frequency of the switching regulator is above a human audible frequency range.

52. The switching regulator of claim 50 wherein the first and second ranges of the feedback signal correspond to first and second ranges of on-time values of a drive signal generated by the control circuit to switch the power switch.

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